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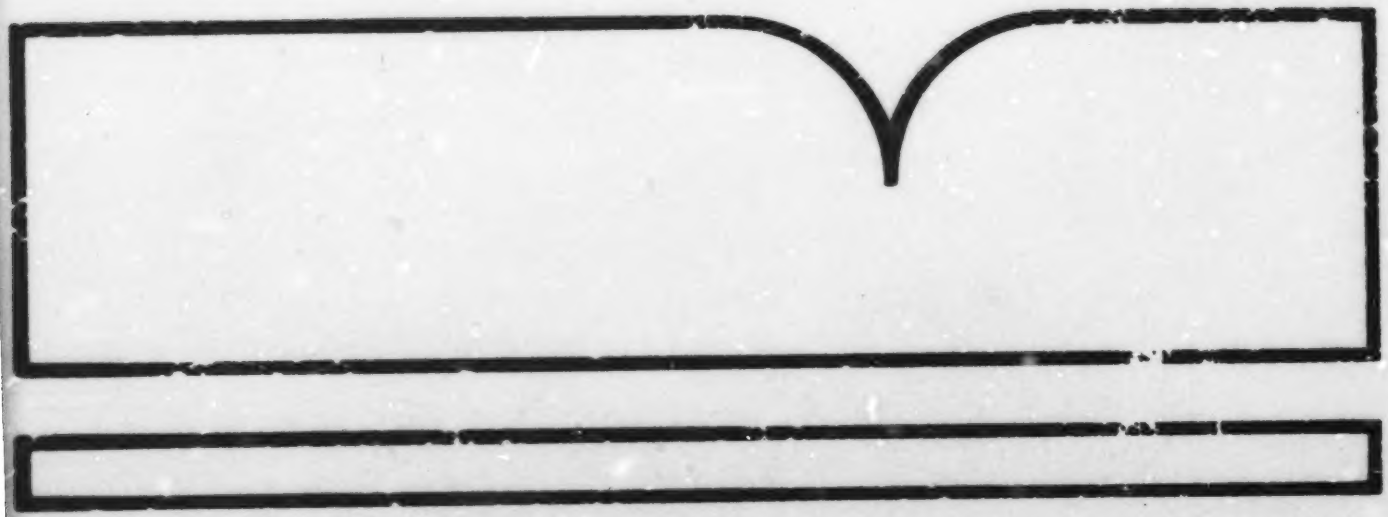

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The stratospheric ozone layer shields the earth from biologically damaging solar ultraviolet radiation. Chlorofluorocarbons (CFCs), used in refrigerants, etc. and halons, used in fire extinguishers, escape into the lower atmosphere and migrate to the stratosphere, destroying the ozone layer by photochemically catalyzing the conversion of ozone to oxygen. Global decreases in stratospheric ozone have been observed in recent years. As a result, UV-B radiation is likely to increase over the next few decades, having a very real potential for significant impacts on marine ecosystems. It would take decades to complete all the research necessary for a definitive assessment of the overall long-term effects of stratospheric ozone depletion. However, a research program focusing on the major uncertainites could, we believe, provide an assessment adequate for informed decision-making within five years.

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STRATOSPHERIC OZONE DEPLETION: IMPLICATIONS FOR MARINE ECOSYSTEMS

By John Hardy and Hermann Gucinski

THE STRATOSPHERIC ozone layer, at an altitude between 10 and 50 km, shields the earth from biologically damaging solar ultraviolet radiation in the 280-320nm wavelength range (UV-B). Chlorofluorocarbons (CFCs), used in refrigerants, foam production, aerosol cans and solvents, and halons used in fire extinguishers escape into the lower atmosphere and migrate to the stratosphere. There they destroy the ozone layer by photochemically catalyzing the conversion of ozone (O_3) to oxygen (O_2).

The greatest depletions have been observed in the austral spring in Antarctica, where depletions have reached 50%.

Global decreases in stratospheric ozone have been observed in recent years (Watson, 1988). Decreases in the northern hemisphere between 1969 and 1986 averaged 0 to 1.9% in summer and 2.3 to 6.2% in winter. In the southern hemisphere depletions between 1978 and 1987 ranged from 2 to 10.6%, depending on latitude. The greatest depletions have been observed in the austral spring in Antarctica, where depletions have reached 50%. The Montreal Protocol took effect in 1988 and was intended to reduce the production of CFCs 50% by 1999 (Crawford, 1987). There is a growing consensus for further reductions, and recommendations of the recent Helsinki Declaration (UNEP, 1989) call for international cooperation for a total elimination of halon and CFC production as soon as possible, but no later than 2000.

Because of the long residence time of different CFC compounds in the atmosphere (8 to 380 years), decreases in total stratospheric ozone are expected to continue into the middle of the next century despite the treaties. Models indicate that an additional global average ozone depletion of 2 to 4% (depending on different trace gas emission scenarios) will occur by the year 2060 (Hoffman and Gibbs, 1988). Our analysis suggests that, if the projected decline occurs with a pattern similar to that of the past, then total decline (1969-2060) at some southern latitudes may reach more than 16% (averaged over seasons). At northern latitudes (53 to 64°), winter depletion would be at least 14% (U.S. EPA, 1988).

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As a result of stratospheric ozone depletion, UV-B radiation is likely to increase over the next few decades. In the sea, the amount of radiation reaching any given depth depends on the total amount reaching the sea surface (largely a function of latitude, season, time of day and cloudiness), the degree of sea-surface roughness (which determines the amount reflected back into space), and the scattering and absorption within the water column. In clear ocean water UV-B radiation is reduced to 1% of the surface level at a depth of about 28m while in productive coastal waters the 1% level may occur at only 1 or 2m (Baker and Smith, 1982). By contrast, visible light will be attenuated to the same 1% level at a depth of 100m in clear oceans, and 15m in more turbid coastal waters.

Increased UV-B radiation has been shown to have a variety of deleterious effects on both individual marine organisms and simulated (mesocosm) marine ecosystems (Worrest, 1986). Models predict that tropical organisms, currently receiving the largest doses of UV radiation, will receive a small percentage increase, while boreal organisms, currently receiving much lower UV doses, will receive much larger percentage increases. Whether or not tropical or boreal organisms will be able to adapt to the predicted increases remains uncertain.

This report will focus on possible effects on marine organisms of a 16% reduction in stratospheric ozone from pre-1970 levels and identify major uncertainties. The 16% case is representative of mid-latitude changes which may occur by 2060.

Effects of UV-B Radiation on Marine Organisms

UV-B is damaging to many biological processes (Jagger, 1985), and shorter wavelengths are generally more damaging than longer wavelengths. Therefore, the biologically effective irradiance is estimated by applying a biological action spectrum where effectiveness is measured as wavelength-specific DNA damage or loss in plant productivity (Caldwell et al., 1986). The UV- B downward spectral irradiance over all angles of the sun during a day is then integrated to obtain the daily biologically effective dose at depth (Smith and Baker, 1989).

Estimates of the dose of biologically damaging UV radiation received by marine organisms involve

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GROUP	EFFECT	TAXA	DAILY DOSE[1] ($J\ m^{-2}$)	DAYS FOR EFFECT	TOTAL DOSE ($J\ m^{-2}$)	REFERENCES
Phytoplankton	20% decrease in primary productivity	SE Pacific populations	24	1	24	Behrenfeld, 1989
	10% decrease in primary productivity	Pooled data on seven species	58	1	58	Worrest *et al.*, 1981
	27% decrease in primary productivity[2]	Natural population in field	25	1	25	Lorenzen, 1979
	Alteration in community species composition	Model of seven species	50	1	150	Worrest *et al.*, 1981
Zooplankton	Significant decrease in survival	Acartia sp.	14	9	125	Dey *et al.*, 1988
		Pseodocalanus spp.	16	6	95	Damkaer *et al.*, 1980,1981
		Shrimp and Euphausiid larvae	22	4	85	Damkaer and Dey, 1983
		Corycaeus anglicus	23	6	140	
		Epilabidocera longipedata	27	5	135	
		Crab zoea	36	6	215	
		Euphausiid adults	36	6	215	
		Calanus pacificus	41	7	285	
	44% reduction in fecundity	Copepod Acartia clausii	10		25 to 50	Karanas *et. al.*, 1981
Benthos	3 to 15% decrease in primary production[3]	Seagrass Halodule wrightii		?	300	Trocine *et al.*, 1981
	100% mortality	Coral	19	?		Scelfo, 1984
	47% decrease in growth	Kelp Ecklonia radiata	13	85	1105	Wood, 1987
Fish	20% decrease in growth (larval length)	Northern anchovy	51	12	616	Hunter *et al.*, 1981
	50% mortality	Northern anchovy	50	12	605	Hunter *et al.*, 1981

[1]Increase above ambient, DNA effective normalized to 280nm
[2]Based on measurement of increase when ambient UV-B is excluded
[3]Our estimate based on converting PI to DNA action spectra

Table 1: Effects of UV-B Radiation on Marine Organisms

considerable uncertainty (Smith and Baker, 1989). Uncertainties result from limitations in instrument sensitivity, changes in sea state (surface reflectance) and cloud conditions. A general paucity of data on the effects of UV radiation on organisms, including their vertical distribution and movements within the water column, further complicates the picture (Voytek, 1989). Also, the use of different exposure methodologies, action spectra and end points (damage functions) for effects, makes comparing the results of different studies difficult.

Predicting biological effects over the wide range of seasons, latitudes, water types and ozone depletions is beyond the scope of this paper. However, for clear water at mid-latitudes in summer, a 16% ozone depletion would result in additional daily UV-B irradiances of about 45 $J_{DNA}\ m^{-2}$ at the surface (a 47% increase) and 31 $J_{DNA}\ m^{-2}$ at a depth of 1 meter (U.S. EPA, 1988). What would be the effect of such an increase on marine organisms? Currently available data suggest that a variety of marine organisms are impacted significantly by very similar doses of increased UV-B radiation and that a reasonable estimate of effects, at least on individual organisms, can be made. In fact, seventeen measurements spanning a wide variety of organisms, exposure conditions and locations all suggest that an increase in daily UV-B dose of 30 (SD=15) $J_{DNA}\ m^{-2}$ can be expected to have a variety of negative impacts (Table 1). In this paper, energy data have been weighted by a DNA action spectrum (Caldwell *et al.*, 1986) and, where possible, they have been normalized to 280nm.

Phytoplankton: The effects of stratospheric ozone depletion on primary productivity are discussed in some detail elsewhere in this issue (Smith and Baker, 1989). Effects of UV-B radiation on phytoplankton occur in response to radiation doses similar to those which are effective for other marine organisms (i.e. 24 to 50 $J_{DNA} m^{-2} d^{-1}$) (Table 1). However, considerable uncertainty remains in extrapolating from short-term measured effects on isolated populations to large scale planktonic ecosystems. This is in part exacerbated by our poor knowledge of long-term responses of populations to UV-B increases (Jokiel and York, 1984). The possibility remains that negative effects of UV radiation could be enhanced in the presence of other stressors or reduced through pigmentation or other protective mechanisms (U.S. EPA, 1988). Little is known regarding the rate at which phytoplankton could adapt (if at all) to in-

creases in UV-B radiation that may occur over the next decade, or the degree to which phytoplankton species composition may change as a result.

Zooplankton: In response to a 16% ozone reduction, marine zooplankton (depending on their seasonal occurrence and depth distribution) could be significantly impacted by UV-B radiation. The predicted increase in daily UV-B irradiance within the upper 1 to 2m (30 to 45 J_{DNA} m^{-2}) would exceed the daily dose found to cause a significant reduction in survival of most zooplankton species examined (Table 1).

Marine zooplankton exhibit a threshold UV-B dose rate. Below this threshold little or no damage occurs and photorepair mechanisms, activated by longer wavelength UV-A and visible light, minimize effects (Dey *et al.*, 1988).

Larval shrimp (*Pandalus platyceros*) exhibit a mortality threshold of 22 J_{DNA} m^{-2} day^{-1} (DNA weighted 3 hr day^{-1} exposure) (Damkaer and Dey, 1983). In mid-latitudes this threshold is close to the currently modeled dose near the surface of the sea in spring, but is exceeded during the longer days of summer.

Increased UV-B radiation has a very real potential for significant impacts on marine ecosystems.

Adult euphausids (*Thysanoessa raschii*) have a threshold sensitivity to UV-B of 36 J_{DNA} m^{-2} day^{-1} for a similar 3-hr day^{-1} exposure (Damkaer and Dey, 1983). These thresholds are higher than those produced by existing and anticipated ozone levels for spring spawners, but well below the 150 J_{DNA} m^{-2} day^{-1} possible at similar latitudes in July, even without ozone depletion.

Benthos: Shallow water benthic communities will be affected by predicted increases in UV-B radiation. Rooted aquatic vegetation, such as sea grasses, are known to have widely differing UV-B sensitivity (Trocine *et al.*, 1981). The growth of kelp (*Ecklonia radiata*) decreased 63% in response to an 80% increase in daily UV-B radiation (Wood, 1987). Tropical coral reefs, which depend on the viability of the associated photosynthetic zooxanthellae (Jokiel, 1980), would be threatened by increased UV-B radiation. Although several corals withstand UV-B radiation by producing UV screening compounds (mycosporine-like amino acids) (Dunlap *et al.*, 1986), many corals and associated fauna could be at risk from future increases in UV-B radiation. The increased UV-B received by the Hawaiian coral (*Montipora verrucosa*) when transplanted from 10 m to 0.2 m depth resulted in 100% mortality, although those transplanted to 3m depth produced a UV screening compound and survived (Scelfo, 1984).

Fish: Anthropogenic stresses, including increased UV-B radiation, are most likely to affect fisheries in two ways—through sublethal or lethal effects on fish eggs and larvae, and through effects on the food chain upon which the larvae depend (Strickland *et al.*, 1985). The bulk of the world's marine harvest of fish, shellfish and crustaceans depends on species that have eggs and larvae that occur at or near the sea surface (Hardy, 1982). Increasing intensities of UV-B radiation near the surface could negatively impact the reproductive potential of some of our most valuable marine resources, including tuna, pollock, cod, halibut and flounder.

An increase in UV-B dose of about 50 J_{DNA} m^{-2} d^{-1} is sufficient to greatly reduce the growth and survival of larval anchovy (Table 1). In Oregon, anchovy larvae occur coincident with high radiation levels between June and August, with a peak in July (Richardson and Pearcy, 1977). Since virtually all anchovy larvae in the northern California, Oregon and Washington shelf area occur within the upper 0.5m, a 16% ozone reduction from pre-1970 levels could be expected to lead to large increases in larval mortality (Chapman and Hardy, 1988). In the Antarctic, the eggs and larvae of fish and krill are found near the surface during the ozone hole season (Voytek, 1989).

Evidence indicates that increased UV-B irradiance could also result in fishery losses through indirect effects on the planktonic food web. Several authors have suggested that fishery yield increases in a power law fashion with increases in primary production (Ryther, 1969; Oglesby 1977; Nixon, 1988). Thus, assuming that fishery yields increase according to productivity raised to the 1.55 power (Nixon, 1988), a 5% decrease in primary production (estimated for a 16% ozone depletion by Smith and Baker, 1980, and Worrest, 1983) will yield reductions in fish yield of approximately 6 to 9%. A 9% reduction in fish yield, if it occurred on a global basis, would represent a loss of about 11 million tons of fish per year.

Risks and Uncertainties

While current data suggest that predicted increases in UV-B radiation could have important negative effects in the marine environment, at least within the upper 1 to 2 m, uncertainties regarding the magnitude of these effects remain large. Indirect effects may occur in the form of altered patterns of predation, competition, diversity and trophic dynamics as species resistant to UV-B radiation replace sensitive species. The combined effects of direct (mortality and fecundity) and indirect (food web) losses cannot as yet be predicted, nor have assessments been made of adaptive strategies or genetic selections that could minimize population or ecosystem effects.

In our opinion, elements of needed research include:

- Defining accurate and appropriate biological action spectra for marine species;
- Determining dose-response relationships for a greater variety of phytoplankton, zooplankton, ichthyoplankton and shallow water benthos, including coral reef and sea grass communities;
- Compiling detailed temporal and spatial distribution data for early life stages to determine exposure;
- Gathering data on the mechanisms and ranges of possible adaptation or genetic selection to increased UV-B radiation;
- Initiating field studies that lead to a better under-

standing and application of laboratory findings;

• Using field research and studies on individual organisms to predict ecosystem-level effects on enhanced UV-B radiation.

In conclusion, increased UV-B radiation has a very real potential for significant impacts on marine ecosystems. It would take decades to complete all the research necessary for a definitive assessment of the overall long-term effects of stratospheric ozone depletion. However, a research program focusing on the major uncertainties could, we believe, provide an assessment adequate for informed decision-making within five years.

References

Baker, K.S. and R.C. Smith, 1982: Bio-optical classification and model of natural waters. *Limnol. Oceanogr., 27(3)*, 500-509.

Behrenfeld, M., 1989: Primary productivity in the southeast Pacific: effect of enhanced ultraviolet-B radiation. M.S. Thesis, Department of General Science, Oregon State University, Corvallis, Oregon. 37 pp.

Caldwell, M.M., L.B. Camp, C.W. Warner and S.D. Flint, 1986: Action spectra and their key role in assessing biological consequences of solar UV-B radiation change. In: *Stratospheric Ozone Reduction, Solar Ultraviolet Radiation and Plant Life*, R.C. Worrest and M.M. Caldwell eds. Springer, 87-111.

Chapman, J. and J.T. Hardy, 1988: Effects of middle ultraviolet radiation on marine fishes. Final Report Oregon State Univ. US EPA Coop. Agrmt. CR-812688-02-0, 31 pp.

Crawford, M., 1987: Landmark ozone treaty negotiated. *Science, 237*, 1557.

Damkaer, D.M. and D.B. Dey, 1983: UV damage and photoreactivation potentials of larval shrimp, *Pandalus platyceros*, and adult euphausids, *Thysanoessa raschii*. *Oecologia, 60*, 169-175.

Damkaer, D.M., D.B. Dey and G.A. Heron, 1981: Dose/dose rate responses of shrimp larvae to UV-B radiation. *Oecologia, 48*, 178-182.

Damkaer, D.M., D.B. Dey, G.A. Heron and E.F. Prentice, 1980: Effects of UV-B radiation on near surface zooplankton of Puget Sound. *Oecologia, 44*, 149-158.

Dey, D.B., D.M. Damkaer and G.A. Heron, 1988: UV-B dose/dose-rate responses of seasonally abundant copepods of Puget Sound. Oecologia, 76, 321-329.

Dunlap, W.C., B.E. Chalker, and J.K. Oliver, 1986: Bathymetric adaptations of reef-building corals at Davies Reef, Great Barrier Reef, Australia. III. UV-B absorbing compounds. *J. Exp. Mar. Biol. Ecol. 104*, 239-248.

Green, A.E.S., K.R. Cross and L.A. Smith, 1980: Improved analytic characterization of ultraviolet skylight. *Photochem. and Photobiol., 31*, 59-65.

Hardy, J.T., 1982: The sea surface microlayer: biology, chemistry and anthropogenic enrichment. *Prog. Oceanog., 11*, 307-328.

Hoffman, J.S. and M.J. Gibbs, 1988: Future concentrations of stratospheric chlorine and bromine. U.S. Environmental Protection Agency. Office of Air and Radiation. EPA 400/1-88/005. August, 63 pp.

Hunter, J.R., S.E. Kaup and J.H. Taylor, 1981: Effects of solar and artificial ultraviolet-B radiation on larval Northern Anchovy. *Engraulis mordax. Photochem. and Photobiol., 34*, 477-486.

Jagger, J., 1985: *Solar-UV Actions on Living Cells*. Praeger Publishers, New York, N.Y. 202 pp.

Jokiel, P.L., 1980: Solar ultraviolet radiation and coral reef epifauna. *Science, 207*, 1069-1071.

Jokiel, P.L. and R.H. York, 1984: Importance of ultraviolet radiation in photoinhibition of microalgae growth. *Limnol. Oceanogr., 29(1)*, 192-199.

Karanas, J.J., R.C. Worrest and H. Van Dyke, 1981: Impact of UV-B radiation on the fecundity of the copepod *Acartia clausii*. *Marine Biology, 65*, 125-133.

Lorenzen, C.J., 1979: Ultraviolet radiation and phytoplankton photosynthesis. *Limnol. Oceanogr., 24(6)*, 1117-1120.

Maugh, T.H., II, 1980: Ozone depletion would have dire effects. *Science, 207*, 394-395.

Nixon, S.W., 1988: Physical energy inputs and the comparative ecology of lake and marine ecosystems. *Limnol. Oceanogr., 33(4, pt 2)*, 1005-1025.

Oglesby, R.T., 1977: Relationships of fish yield to lake phytoplankton standing crop, production and morphoedaphic factors. *J. Fish. Res. Board Can., 34*, 2271-2279.

Richardson, S.L. and W.G. Pearcy, 1977: Coastal and oceanic fish larvae in an area of upwelling off Yaquina Bay, Oregon. *Fish. Bull., 75*, 125-146.

Ryther, J.H., 1969: Photosynthesis and fish production in the sea. *Science., 166*, 72-76.

Scelfo, G.M., 1984: The effects of solar ultraviolet radiation upon a Hawaiian reef coral. Abstract. Annual Meeting of the American Society of Zoologists. Denver, Colorado, December 27-30. *Amer. Zool. 24(3)*, 79A.

Smith, R.C. and K.S. Baker, 1980: Stratospheric ozone, middle ultraviolet radiation, and carbon-14 measurements of marine productivity. *Science, 208*, 592-593.

Smith, R.C. and K.S. Baker, 1989: Stratospheric ozone, middle ultraviolet radiation and phytoplankton productivity. *Oceanogr. Mag 2(2)*, 4-10.

Strickland, R.M., D.J. Grosse, A.I. Stubin, G.K. Ostrander and T.H. Sibley, 1985: Definition and characterization of data needs to describe the potential effects of increased atmospheric CO_2 on marine fisheries from the Northeast Pacific Ocean. Report to U.S. Department of Energy (DOE/NBB-0075), Contract No. W-7405-ENG-48. School of Fisheries, University of Washington, Seattle. 139 pp.

Trocine, R.P., J.D. Rice and G.N. Wells, 1981: Inhibition of seagrass photosynthesis by ultraviolet-B radiation. *Plant Physiol., 68*, 74-81.

UNEP, United Nations Environmental Program, 1989: First Meeting of Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer. Helsinki Declaration on the Protection of the Ozone Layer. Helsinki, Finland, 2-5 May. UNEP, New York.

U.S. EPA. Environmental Protection Agency, 1988: *Ecological Effects of Stratospheric Ozone Depletion*. Stratospheric Ozone Research Group. Environmental Research Laboratory, Corvallis, Oregon. 66 pp.

Voytek, M.A., 1989: Ominous future under the ozone hole: Assessing biological impacts in Antarctica. Environmental Defense Fund, 69 pp.

Watson, R.T., ed., 1988: *Ozone Trends Panel. Execute Summary*. Washington, D.C., National Aeronautics and Space Administration, Report No. 1208, August 1988, 208 pp.

Wood, W.F., 1987: Effect of solar ultra-violet radiation on the kelp Ecklonia radiata. *Mar. Biol. 96*, 143-150.

Worrest, R. C., 1982: Review of literature concerning the impact of UV-B radiation upon marine organisms. The Role of Solar Ultraviolet Radiation in Marine Ecosystems. J. Calkins, ed., Plenum Publishing, 429-457.

Worrest, R.C., 1983: Impact of solar ultraviolet-B radiation (290-320 nm) upon marine mircroalgae. *Physiol Plant., 58*, 428-434.

Worrest, R.C., 1986: The effect of solar UV-B radiation on aquatic systems: an overview. Effects of Changes in Stratsopheric Ozone and Global Climate, Vol. 1, Overview. J.G. Titus, ed. U.S. Environmental Protection Agency and United Nationas Environmental Programme, 175-191.

Worrest, R.C., B.E. Thomson and H. Van Dyke, 1981: Impact of UV-B radiation upon estuarine microcosms. *Photochem. and Photobiol., 33*, 861-867. ❑

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